US009322579B2

(12) **United States Patent**
**Morimoto et al.**

(10) **Patent No.: US 9,322,579 B2**
(45) **Date of Patent: Apr. 26, 2016**

(54) **THERMO-MAGNETIC CYCLE APPARATUS**

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( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 217 days.

(21) Appl. No.: **14/248,648**

(22) Filed: **Apr. 9, 2014**

(65) **Prior Publication Data**

US 2014/0305138 A1 Oct. 16, 2014

(30) **Foreign Application Priority Data**

Apr. 12, 2013 (JP) ................................ 2013-084351

(51) **Int. Cl.**
***F25B 21/02*** (2006.01)
***F25B 21/00*** (2006.01)

(52) **U.S. Cl.**
CPC ......... ***F25B 21/00*** (2013.01); *F25B 2321/0022* (2013.01); *Y02B 30/66* (2013.01)

(58) **Field of Classification Search**
CPC ......... F25B 21/00; F25B 21/02; Y02B 30/66; H01L 35/30
USPC .................................................. 62/3.1, 3.3, 6
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,509,334 A * 4/1985 Nakagome .............. F25B 21/00 165/104.21
4,599,866 A * 7/1986 Nakagome .............. F25B 21/00 505/889
4,829,770 A * 5/1989 Hashimoto .............. C09K 5/16 62/3.1
2005/0120720 A1 * 6/2005 Fang ........................ F25B 21/00 62/3.1
2007/0125094 A1 6/2007 Iwasaki et al.
2011/0067416 A1 * 3/2011 Chang ........................ F24J 3/00 62/3.1
2012/0285179 A1 11/2012 Morimoto et al.
2012/0291453 A1 11/2012 Watanabe et al.
2013/0298571 A1 11/2013 Morimoto et al.

FOREIGN PATENT DOCUMENTS

JP 2007-147209 6/2007
JP 2012-255642 12/2012

OTHER PUBLICATIONS

Office Action dated Mar. 10, 2015 in corresponding Japanese Application No. 2013-084351.

* cited by examiner

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(57) **ABSTRACT**

A magneto-caloric effect type heat pump apparatus provides a thermo-magnetic cycle apparatus. A magnetic field modulating device has a rotary permanent magnet. By rotating the permanent magnet, magnetic field applied to a magneto-caloric element is modulated alternatively in a magnetized state and a demagnetized state. A magnetized period, when the magnetic field is applied, is shorter than a demagnetized period, when the magnetic field is removed. Thereby, it is possible to reduce weight of the magnetic field modulating device having the permanent magnet. The magneto-caloric element has a heat exchange portion which varies heat exchanging efficiency depending on flow directions of a heat transport medium. The heat exchanging efficiency in the magnetized period is higher than the heat exchanging efficiency in the demagnetized period. Therefore, it is possible to provide sufficient heat exchanging quantity even in a short magnetized period.

**12 Claims, 5 Drawing Sheets**

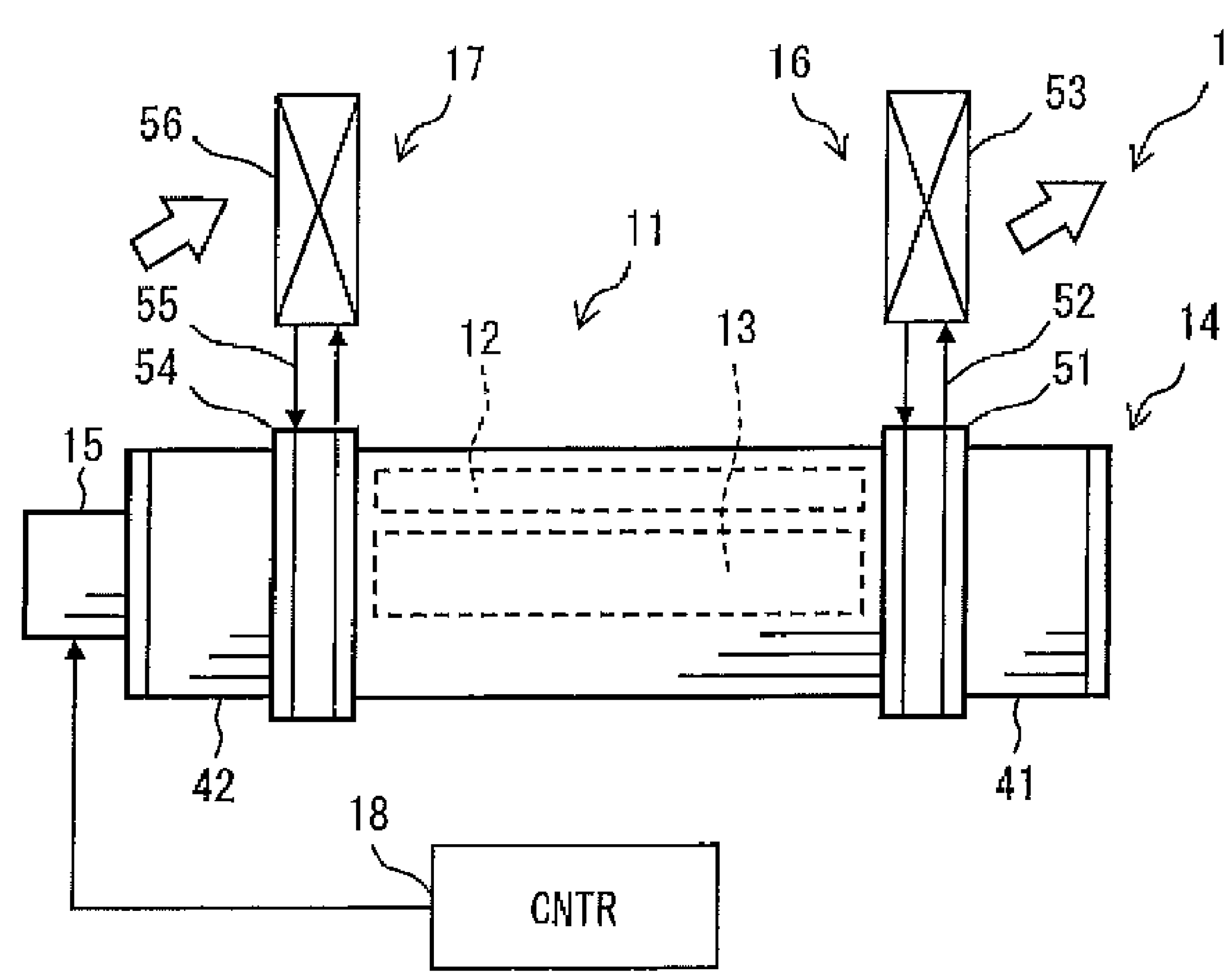


FIG. 1

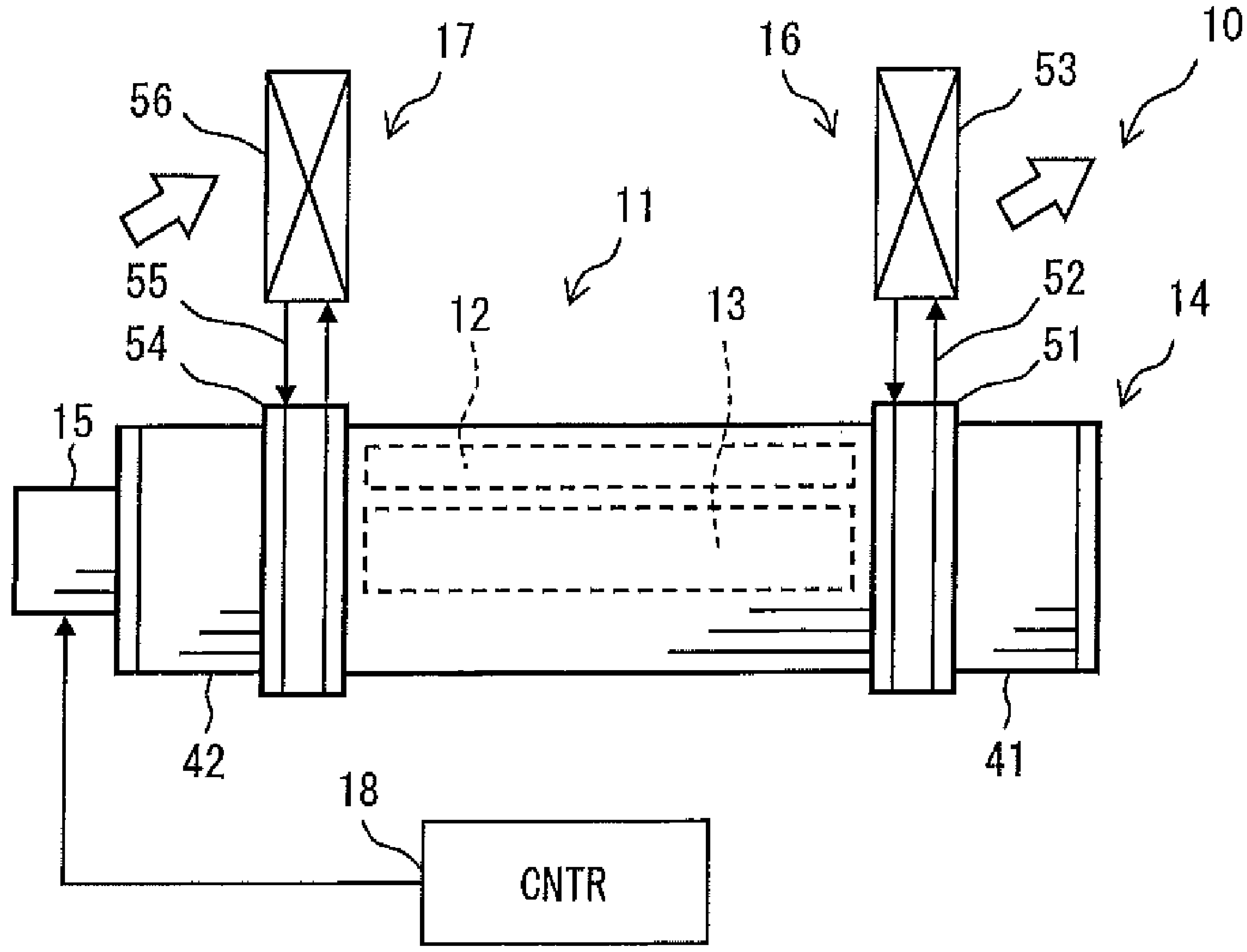

17
16
10
56
53
11
55
52
14
12
13
54
51
15
42
41
18
CNTR

FIG. 2

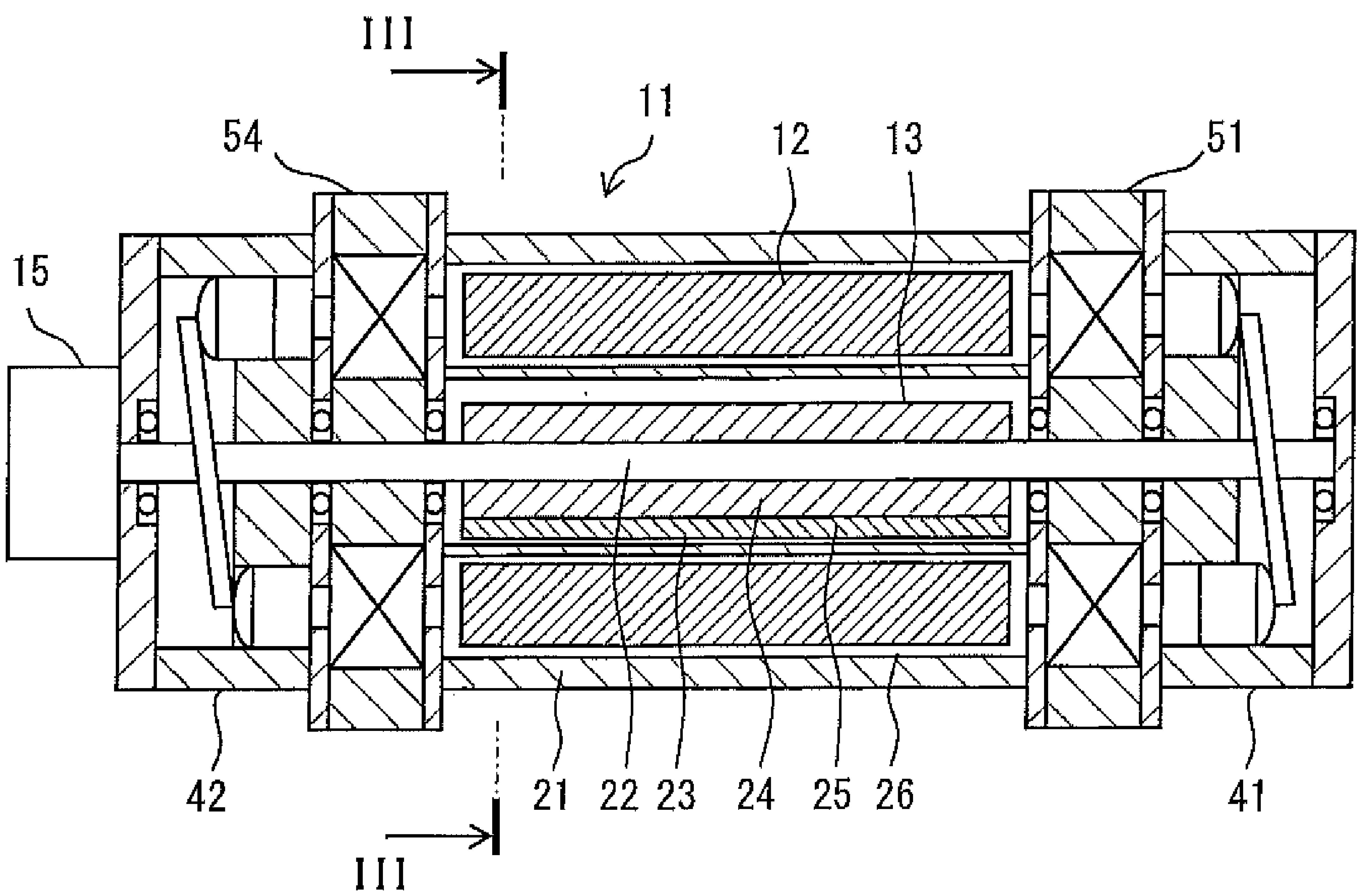

III
11
54
12
13
51
15
42
21
22
23
24
25
26
41
III

FIG. 3

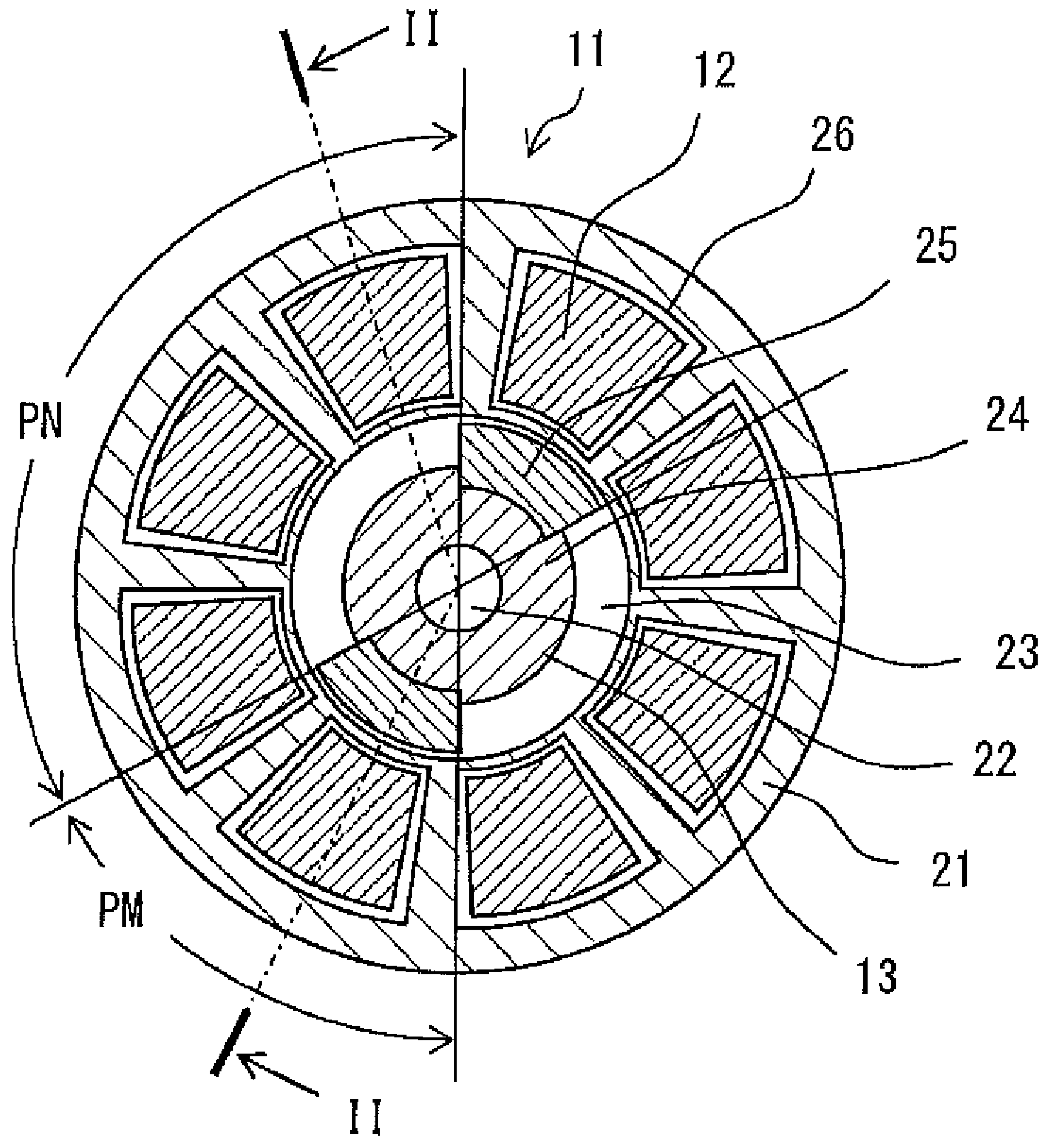



FIG. 4

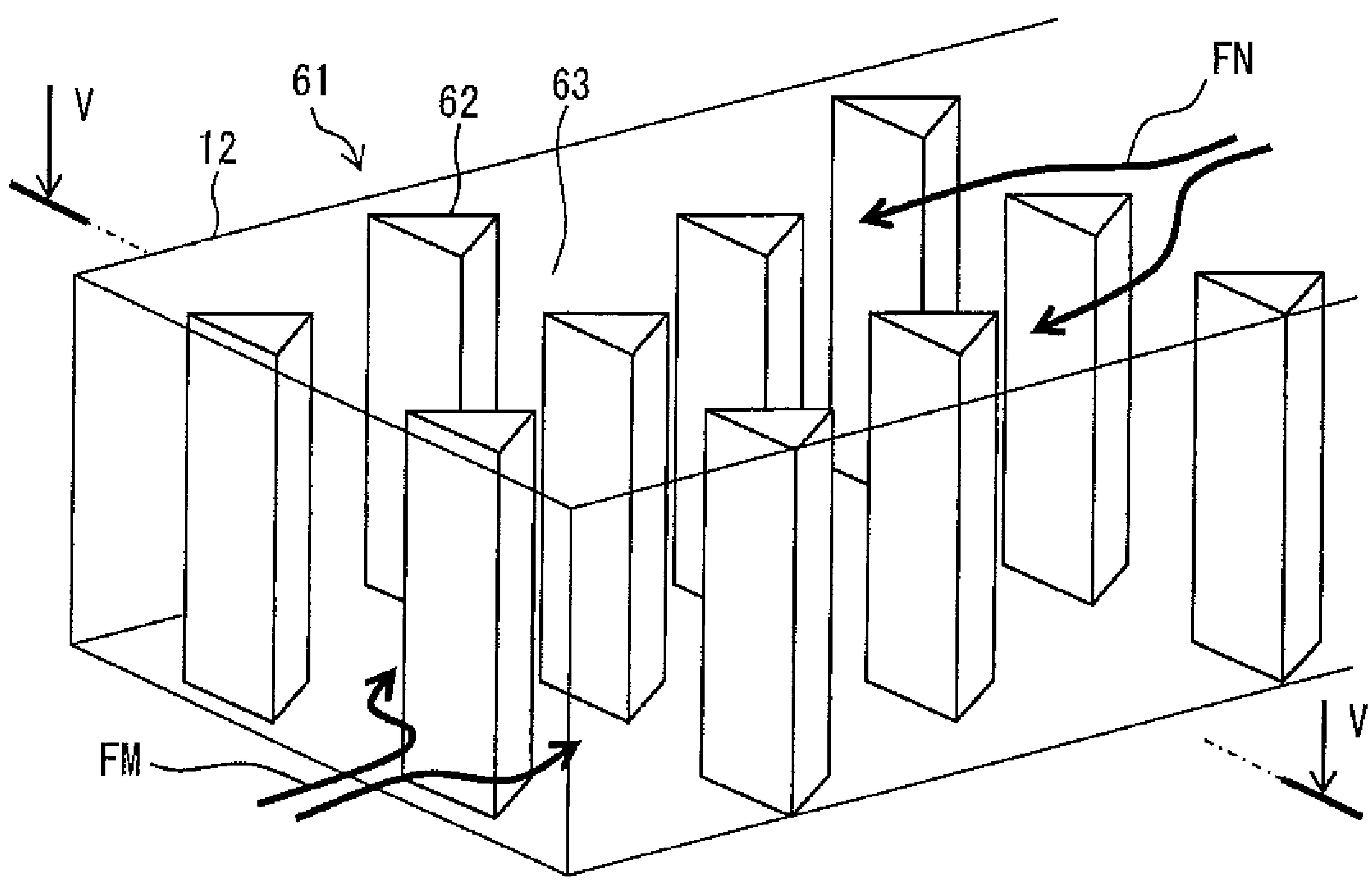


FIG. 5

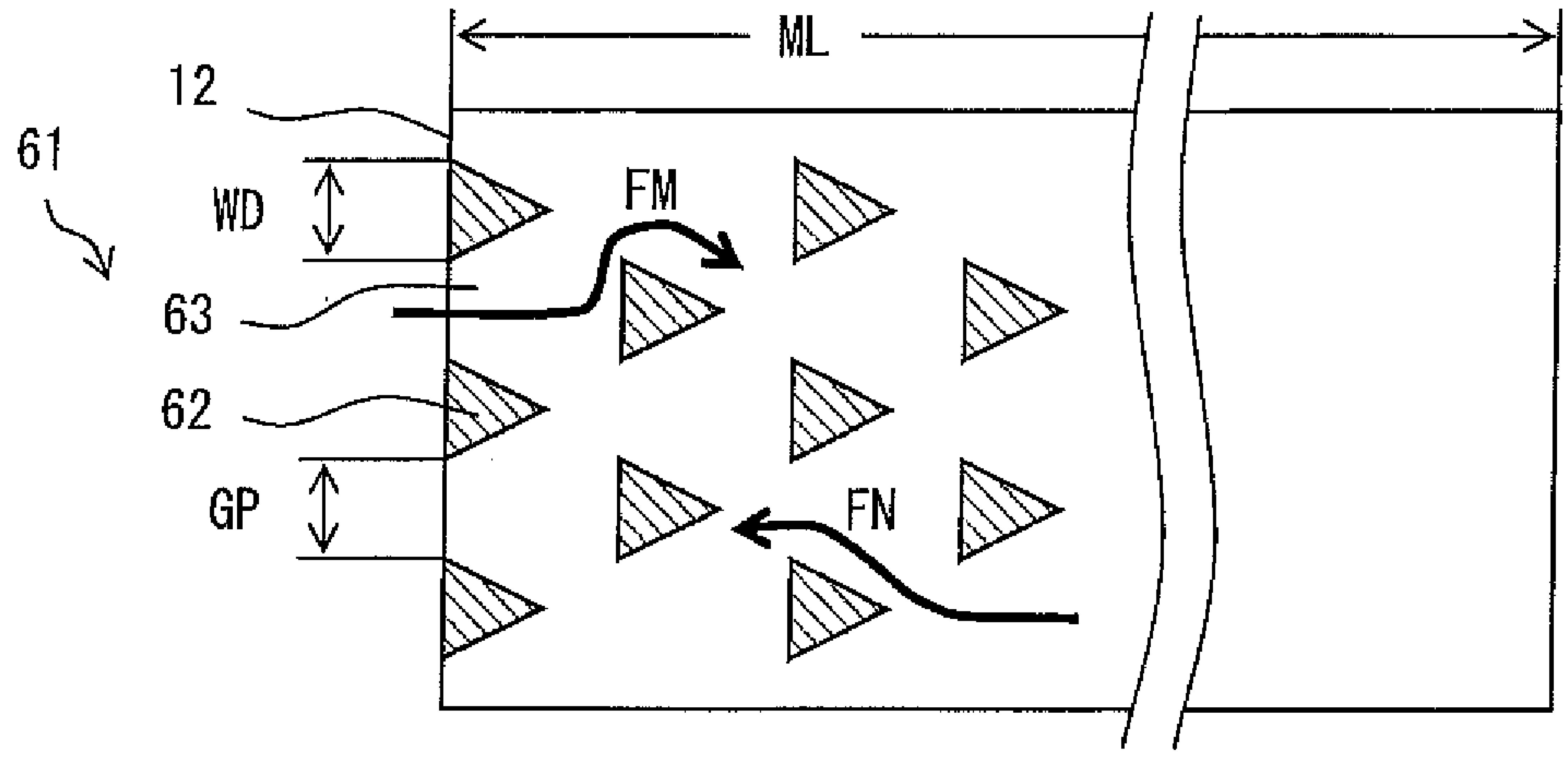



FIG. 6

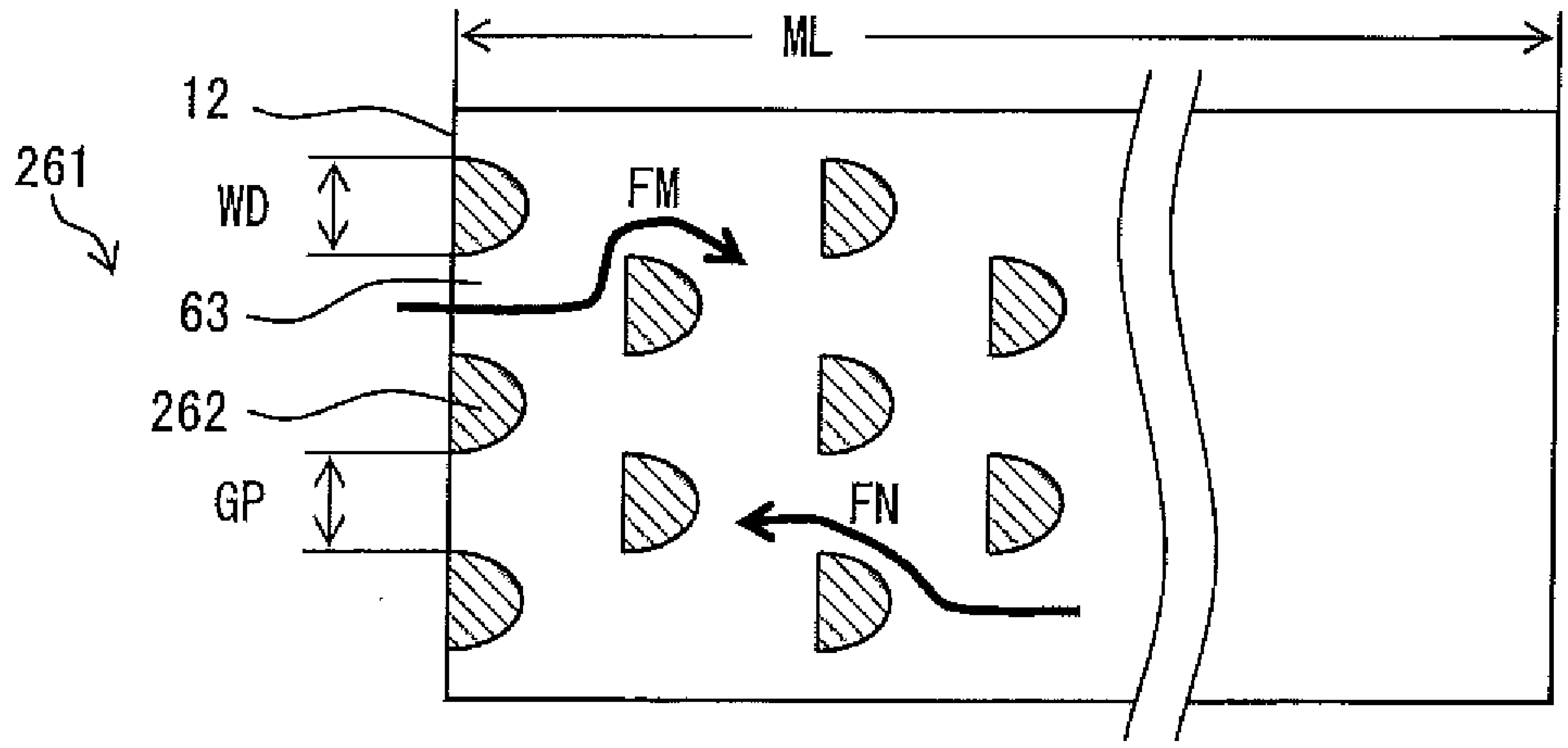



FIG. 7

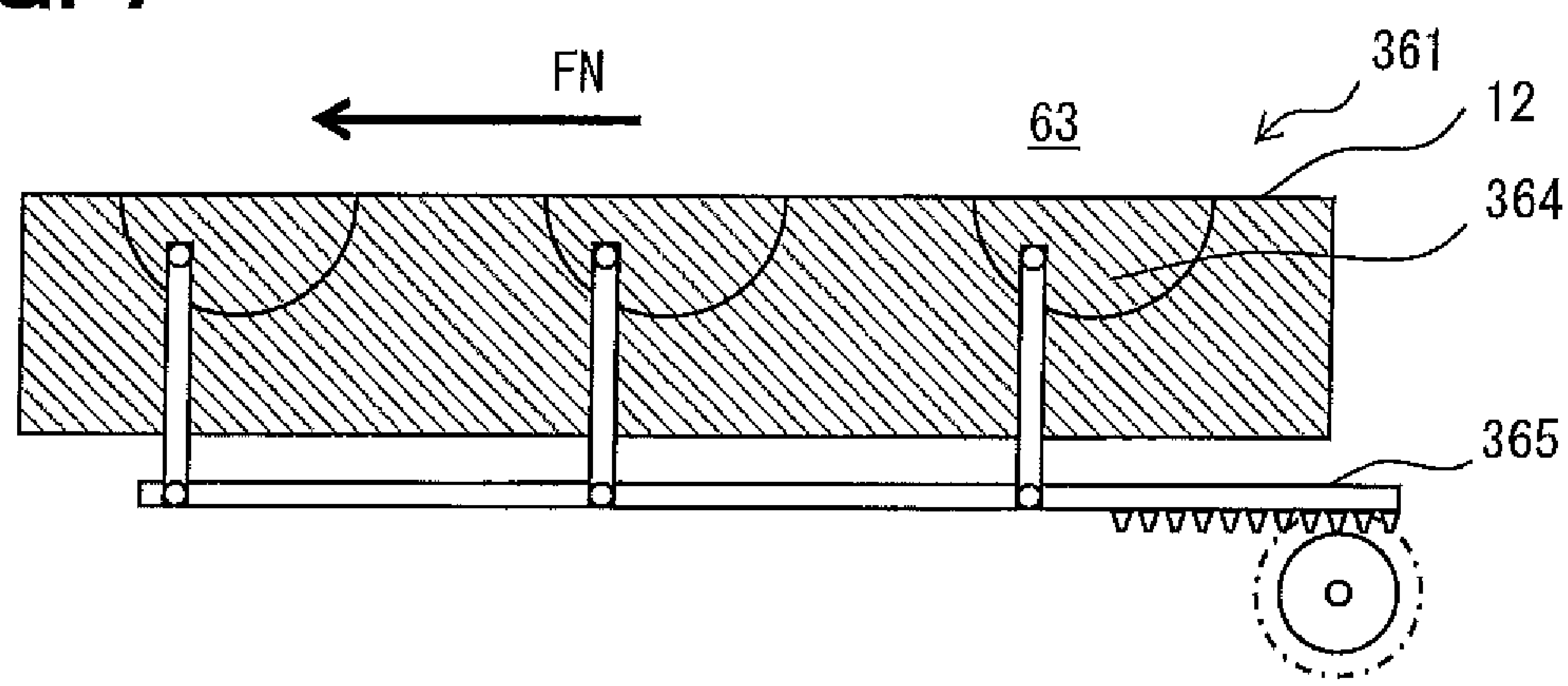


FIG. 8

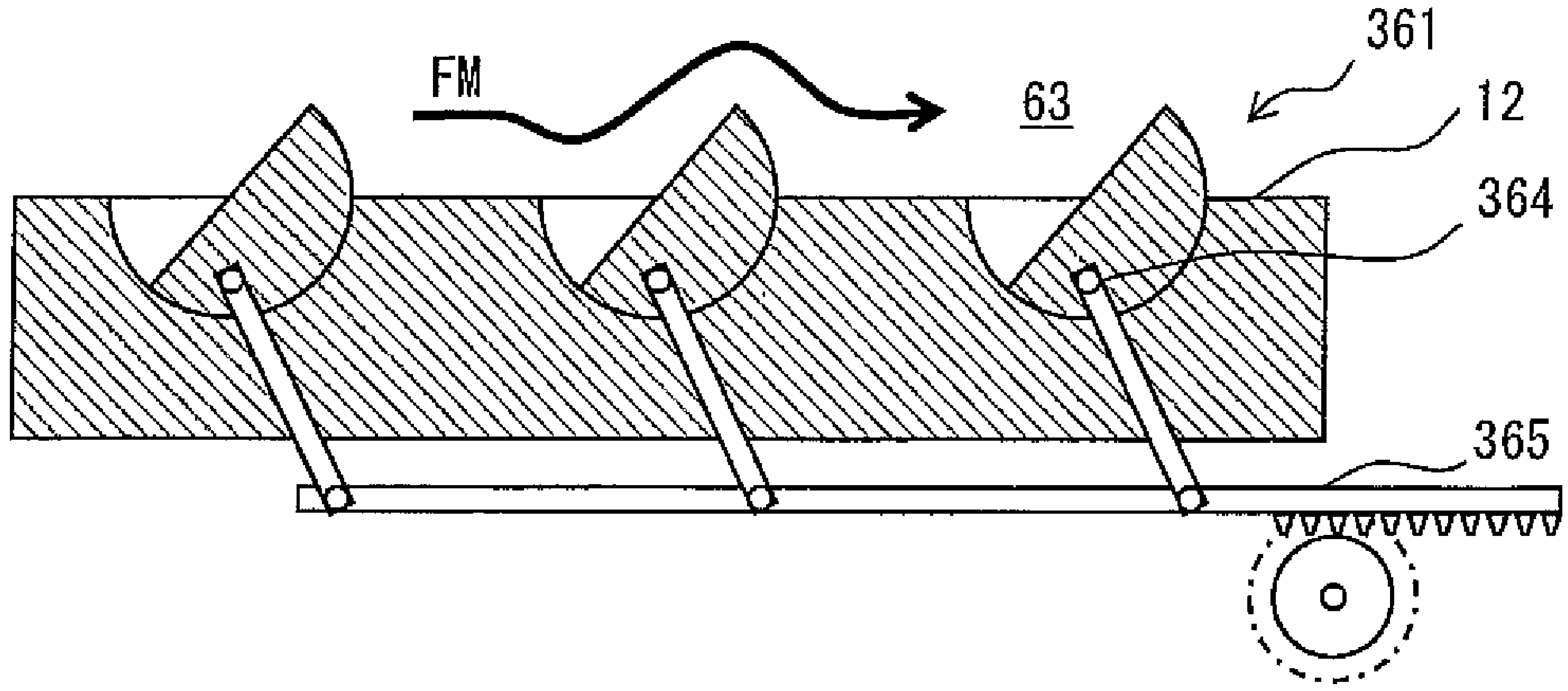



FIG. 9

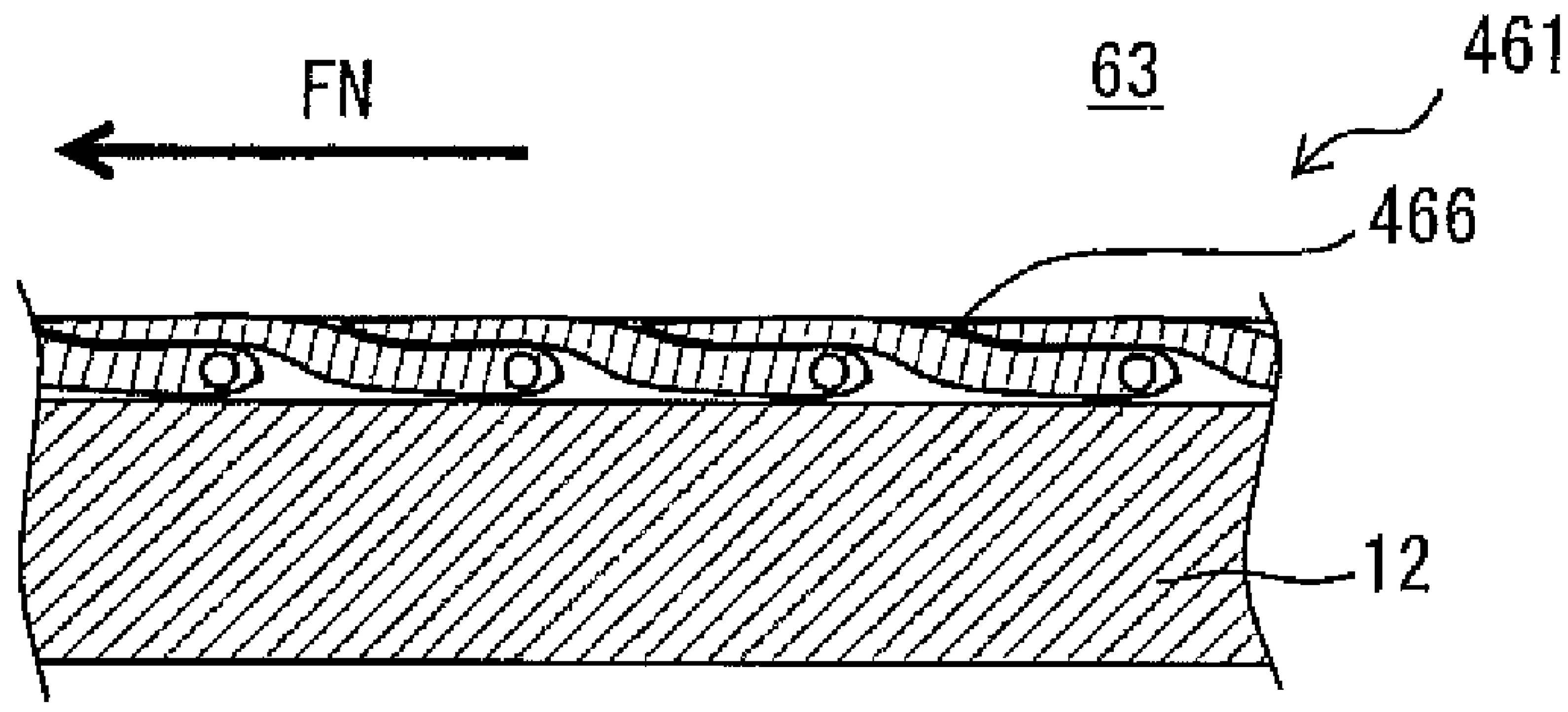



FIG. 10

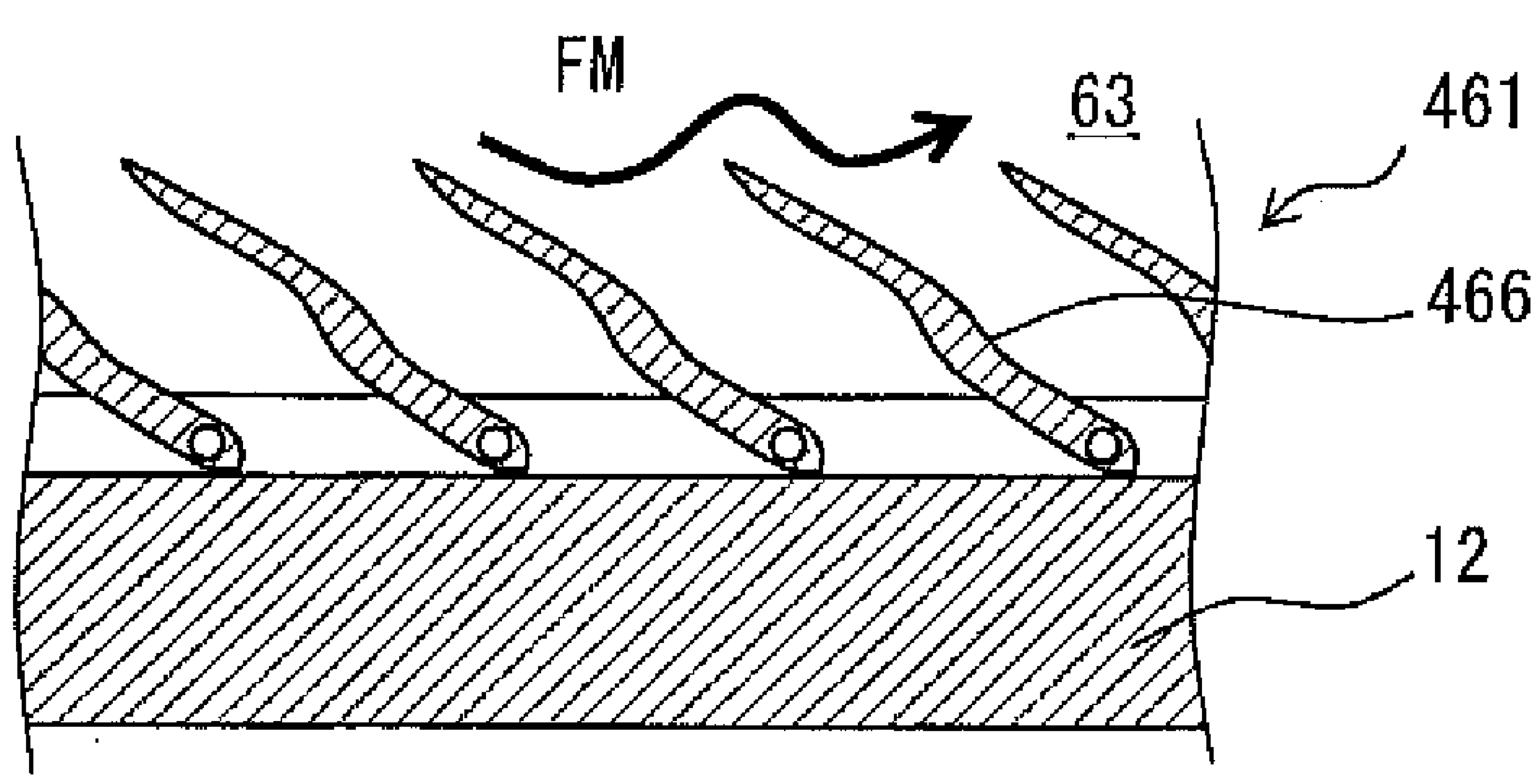


FIG. 11

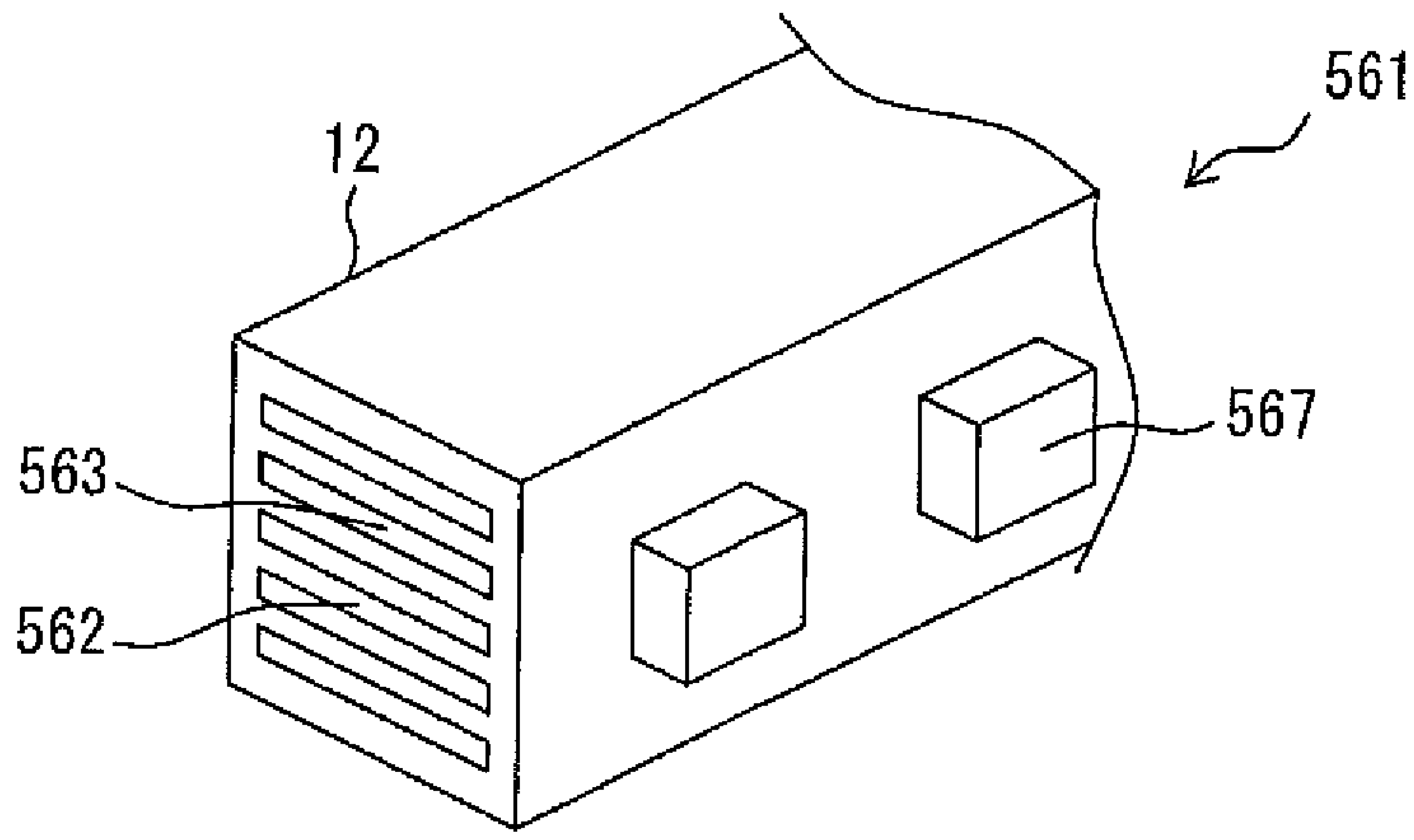
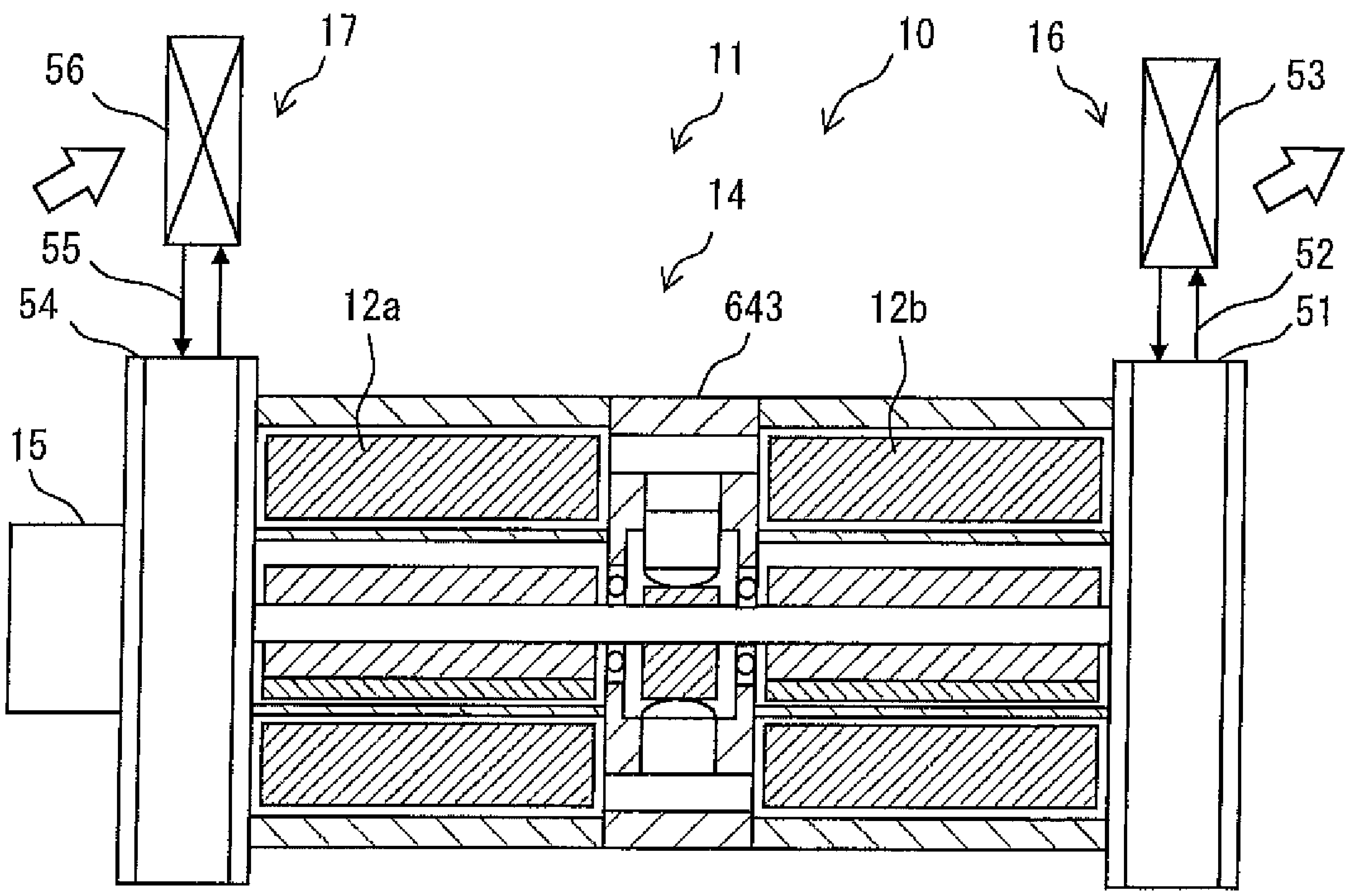



FIG. 12



# THERMO-MAGNETIC CYCLE APPARATUS

## CROSS REFERENCE TO RELATED APPLICATION

This application is based on Japanese Patent Application No. 2013-84351 filed on Apr. 12, 2013, the disclosure of which is incorporated herein by reference in its entirety.

## TECHNICAL FIELD

The present disclosure relates to a thermo-magnetic cycle apparatus using magneto-caloric effect of magnetic material. The thermo-magnetic cycle apparatus may be used as a magneto-caloric effect type heat pump apparatus.

## BACKGROUND

JP2012-255642A and JP4557874B disclose a magneto-caloric effect type heat pump apparatus which is one embodiment of the thermo-magnetic cycle apparatus which uses a temperature characteristic of a magnetic substance. The documents propose heat pump apparatuses using the magneto-caloric effect of the magneto-caloric element which is a magnetic substance. The proposed apparatuses have a magnetic field modulating device having a permanent magnet and yoke members forming a magnetic path. The magnetic field modulating device cyclically and alternately switches a state of external magnetic field. The magnetic field modulating device switches between a state where the external magnetic field is applied to the magneto-caloric element and a state where the external magnetic field is removed from the magneto-caloric element. The state where the external magnetic field is applied may also be referred to as a magnetized state. The state where the external magnetic field is removed may also be referred to as a demagnetized state. The magnetic field modulating device modulates periodically strength of the external magnetic field which is applied to the magneto-caloric element by rotating magnetic members including the permanent magnet.

## SUMMARY

The magnetic circuits disclosed in the documents are large and heavy. For this reason, the thermo-magnetic cycle apparatus had large body and heavy weight. It such view points, it is demanded to improve the thermo-magnetic cycle apparatus.

It is an object of the present disclosure to provide a lightweight thermo-magnetic cycle apparatus.

It is another object of the present disclosure to provide a small thermo-magnetic cycle apparatus.

It is still another object of the present disclosure to provide a thermo-magnetic cycle apparatus which can use a magnetic field modulating device that provides a magnetizing period shorter than a demagnetizing period.

The present disclosure employs the following technical means, in order to attain the above-mentioned object.

According to a disclosure, a thermo-magnetic cycle apparatus is provided. The apparatus comprised a magneto-caloric element which generates heat dissipation and heat absorption in response to strength change of an external magnetic field. The apparatus also comprises a magnetic field modulating device which modulates the external magnetic field applied to the magneto-caloric element. The device modulates the external magnetic field so that a magnetized period and a demagnetized period are periodically altered. The magnetized period is when the magneto-caloric element is placed in a strong external magnetic field. The demagnetized period is when the magneto-caloric element is placed in a weak external magnetic field which is weaker than that in the magnetized period. The device modulates the external magnetic field so that the magnetized period is shorter than the demagnetized period.

According to the above arrangement, since the magnetized period is shorter than the demagnetized period, it is possible to reduce weight of a magnetism source for supplying the external magnetic field.

## BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the present disclosure will become more apparent from the following detailed description made with reference to the accompanying drawings. In the drawings:

FIG. **1** is a block diagram of a magneto-caloric effect type heat pump apparatus (henceforth a MHP apparatus) according to a first embodiment;

FIG. **2** is a cross-sectional view of the MHP apparatus according to the first embodiment;

FIG. **3** is a cross-sectional view of the MHP apparatus according to the first embodiment;

FIG. **4** is a perspective view of a magneto-caloric element according to the first embodiment;

FIG. **5** is a cross-sectional view of a magneto-caloric element according to the first embodiment;

FIG. **6** is a cross-sectional view of a magneto-caloric element according to a second embodiment;

FIG. **7** is a cross-sectional view of a magneto-caloric element according to a third embodiment;

FIG. **8** is a cross-sectional view of a magneto-caloric element according to the third embodiment;

FIG. **9** is a cross-sectional view of a magneto-caloric element according to a fourth embodiment;

FIG. **10** is a cross-sectional view of a magneto-caloric element according to the fourth embodiment;

FIG. **11** is a perspective view of a magneto-caloric element according to a fifth embodiment; and

FIG. **12** is a cross-sectional view of the MHP apparatus according to a sixth embodiment.

## DETAILED DESCRIPTION

Embodiments of the present disclosure are explained referring to drawings. In the embodiments, the same parts and components as those in each embodiment are indicated with the same reference numbers and the same descriptions will not be reiterated. In a case that only a part of component or part is described, other descriptions for the remaining part of component or part in the other description may be incorporated. Components and parts corresponding to the components and parts described in the preceding description may be indicated by the same reference number and may not be described redundantly. The embodiments may be partially combined or partially exchanged in some forms which are clearly specified in the following description. In addition, it should be understood that, unless trouble arises, the embodiments may be partially combined or partially exchanged each other in some forms which are not clearly specified.

### First Embodiment

FIG. **1** is a block diagram showing a vehicle air-conditioner **10** for vehicle according to a first embodiment that practices the invention. The vehicle air-conditioner **10** has a magneto-caloric effect type heat pump apparatus **11**. Hereinafter, the magneto-caloric effect type heat pump apparatus **11** may be referred as MHP apparatus **11**. The MHP apparatus **11** provides the thermo-magnetic cycle apparatus.

In this specification, the word of the heat pump apparatus is used in a broad sense. That is, the word of the heat pump apparatus includes both of a heat pump apparatus using cold energy and a heat pump apparatus using hot energy. The heat pump apparatus using cold energy may correspond to a refrigerating cycle apparatus. The word of the heat pump apparatus may be used as a concept that includes the refrigerating cycle apparatus.

The MHP apparatus **11** has a magneto-caloric effect element. Hereinafter, the magneto-caloric effect element may be referred to as MCE element. The MCE element **12** produces both heat generation and heat absorption in response to strength of an external magnetic field. The MCE element **12** generates heat in response to applying the external magnetic field, and absorbs heat in response to removing the external magnetic field. When the external magnetic field is applied to the MCE element **12**, electron spins gather in the direction of the magnetic field. At this time, magnetic entropy decreases and the temperature is raised by emitting heat. When the external magnetic field is removed from the MCE element **12**, the electron spins become to have disordered state. At this time, magnetic entropy increases and the temperature is lowered by absorbing heat. The MCE element **12** is made of magnetic substance which has a high magneto-caloric effect in an ordinary temperature region. For example, the MCE element **12** may be made of a gadolinium(Gd)-base material or lanthanum-iron-silicon compound. Alternatively, a mixture of manganese, iron, phosphorus, and germanium may be used.

One MCE element **12** and components relevant to it provide a magneto-caloric element unit. The magneto-caloric element unit may be referred to as an MCD unit (Magneto-Caloric effect Device unit.) The MHP apparatus **11** uses magneto-caloric effect of the MCE element **12**. The MHP apparatus **11** has a magnetic field modulating (MFM) device **13** and a heat transporting device **14** for operating the MCE element **12** as an AMR (Active Magnetic Refrigeration) cycle.

The MFM device **13** applies the external magnetic field to the MCE element **12**, and varies the strength of the external magnetic field applied to the MCE element **12**. The MFM device **13** periodically switches the magnetized state where the MCE element **12** is placed in a strong magnetic field and the demagnetized state where the MCE element **12** is placed in a weak magnetic field or a zero magnetic field. The MFM device **13** modulates the external magnetic field so that the external magnetic field periodically repeats a magnetized period PM when the MCE element **12** is placed in a strong magnetic field and a demagnetized period PN when the MCE element **12** is placed in the external magnetic field that is weaker than that in the magnetized period PM. The MFM device **13** is set to provide the magnetized period PM that is shorter (PM<PN) than the demagnetized period PN. The MFM device **13** has a magnetism source for generating the external magnetic field, for example, a permanent magnet, and an electromagnet. The magnetism source is configured to set the magnetized period PM is shorter than the demagnetized period PN.

The heat transporting device **14** has fluid devices for generating flow of a heat transport medium for transporting heat to be dissipated or absorbed by the MCE element **12**. The heat transporting device **14** is a device which generates flow of the heat transport medium so that the heat transport medium flows along the MCE element **12** and performs heat exchange with the MCE element **12**. The heat transporting device **14** generates a bidirectional flow including a flow FM and a flow FN of the heat transport medium. The flow of the heat transport medium is the bidirectional flow FM, FN switched alternately in a synchronizing manner with change of the external magnetic field by the MFM device **13**.

In this embodiment, the heat transport medium which carries out heat exchange to the MCE element **12** is called a primary medium. The primary medium can be provided by fluid, such as anti-freezing solution, water, and oil. The heat transporting device **14** generates a bidirectional flow of the heat transport medium. The heat transporting device **14** alternately changes flow directions of the heat transport medium in a forward and backward manner in a synchronizing manner with an increasing and decreasing changes of the external magnetic field by the MFM device **13**. The heat transporting device **14** may have a pump for generating flow of the heat transport medium. The heat transporting device **14** has pumps **41** and **42** for generating flow of the primary medium. The pumps **41** and **42** supply the bidirectional flow of the primary medium for one MCE element **12**. The pumps **41** and **42** are arranged on both ends of the MCE element **12**. The pumps **41** and **42** are arranged to perform complementarily a suction process and a discharge process.

The MHP apparatus **11** has a motor **15** as a source of power. The motor **15** is the source of power for the MFM device **13**. The motor **15** is the source of power for the heat transporting device **14**.

The MHP apparatus **11** has a high-temperature system **16** which conveys high temperature created by the MHP apparatus **11**. The high-temperature system **16** is also a device which uses the high temperature created by the MHP apparatus **11**. The MHP apparatus **11** has a low-temperature system **17** which conveys low temperature created by the MHP apparatus **11**. The low-temperature system **17** is also a device which uses the low temperature created by the MHP apparatus **11**.

The high-temperature system **16** has a heat exchanger **51** which provides heat exchange between the primary medium and a secondary medium for the high-temperature system **16**. The secondary medium is a heat transport medium used to convey thermal energy in the high-temperature system **16**. The secondary medium can be provided by fluid, such as anti-freezing solution, water, and oil. The high-temperature system **16** has a passage **52** in which the secondary medium flows in a circulating manner. The high-temperature system **16** has a heat exchanger **53** which provides heat exchange between the secondary medium and the other medium. For example, the heat exchanger **53** provides heat exchange between the secondary medium and air. The high-temperature system **16** is also a device which removes heat, i.e., thermal energy, from the high-temperature end, and cools the high-temperature end.

The low-temperature system **17** has a heat exchanger **54** which provides heat exchange between the primary medium and a secondary medium for the low-temperature system **17**. The secondary medium is a heat transport medium used to convey thermal energy in the low-temperature system **17**. The secondary medium can be provided by fluid, such as anti-freezing solution, water, and oil. The low-temperature system **17** has a passage **55** in which the secondary medium flows in a circulating manner. The low-temperature system **17** has a heat exchanger **56** which provides heat exchange between the secondary medium and the other medium. For example, the heat exchanger **56** provides heat exchange between the secondary medium and air. The low-temperature system **17** is also a device which brings heat, i.e., thermal energy, into the low-temperature end, and heats the low-temperature end.

The vehicle air-conditioner **10** is mounted on a vehicle, and carries out temperature control of passenger compartment of the vehicle. Two heat exchangers **53** and **56** provide components of the vehicle air-conditioner **10**. The heat exchanger **53** is a high-temperature-side heat exchanger **53** of which temperature usually reach higher than that of the heat exchanger **56**. The heat exchanger **53** may also be called an indoor heat exchanger **53**. The heat exchanger **56** is a low-temperature-side heat exchanger **56** of which temperature usually reaches lower than that of the heat exchanger **53**. The heat exchanger **56** may also be called an outdoor heat exchanger **56**. The vehicle air-conditioner **10** also has air-system devices such as an air-conditioning duct and fan which are provided to use the high-temperature-side heat exchanger **53** and/or the low-temperature-side heat exchanger **56** for air conditioning.

The vehicle air-conditioner **10** may be used as an air cooling device or an air heating device. The vehicle air-conditioner **10** may have a cooler for cooling air supplied to the compartment and a heater for heating again the air cooled by the cooler. The MHP apparatus **11** may be used as a cold-energy supplying source in the vehicle air-conditioner **10** or a warm-energy supplying source in the vehicle air-conditioner **10**. That is, the high-temperature-side heat exchanger **53** may be used as the heater. The low-temperature-side heat exchanger **56** may be used as the cooler.

When the MHP apparatus **11** is used as the warm-energy supplying source, air passing through the high-temperature-side heat exchanger **53** is supplied to the compartment and is used for heating. At this time, the air which passed the low-temperature-side heat exchanger **56** is discharged to the outside of the vehicle. When the MHP apparatus **11** is used as a cold-energy supplying source, air passing through the low-temperature-side heat exchanger **56** is supplied to the compartment and is used for cooling. At this time, the air which passed the high-temperature-side heat exchanger **53** is discharged to the outside of the vehicle. The MHP apparatus **11** may be used as a dehumidifier system. In this case, air passes through the low-temperature-side heat exchanger **56**, and then, passes the high-temperature-side heat exchanger **53**, and is supplied to the compartment. The MHP apparatus **11** may be used as a warm-energy supplying source both in the summer season and the winter season.

The vehicle air-conditioner **1** has a controller (CNTR) **18**. The controller **18** controls a plurality of controllable components of the vehicle air-conditioner **10**. For example, the controller **18** controls the motor **15** to at least switch the MHP apparatus **11** in an activated mode and a deactivated mode.

The controller **18** is an electronic control unit. The controller **18** is an electrical control unit (ECU). The controller **18** has at least one processing unit (CPU) and at least one memory device (MMR) provided as a storage medium which stores a set of program and data. The controller **18** is provided with a microcomputer having the storage medium readable by a computer. The storage medium is a non-transitory storage medium which stores a program readable by the computer. The storage medium can be provided by a device, such as a solid state memory device and a magnetic disc memory. The controller **18** is provided with one computer, or a set of computer resources linked by a data communication device. The program, when executed by the controller **18**, makes the controller **18** to function as devices described in this specification, and makes the controller **18** to perform methods described in this specification. The controller **18** provides a plurality of various elements. At least a part of those elements may be called as means for performing functions, and, in another aspect, at least a part of those elements may be called as structural blocks or modules.

FIG. **2** is a cross-sectional view of the MHP apparatus **11** according to the first embodiment. FIG. **3** is a cross-sectional view of the MHP apparatus **11** according to the first embodiment. FIG. **2** shows a cross-section on a line shown in FIG. **3**. FIG. **3** shows a cross-section on a line shown in FIG. **2**.

The motor **15** provided as the power source for the MHP apparatus **11** is driven by a battery mounted on the vehicle. The motor **15** rotates the rotor **13** which provides the MFM device **13**. Thereby, the motor **15** and the MFM device **13** creates a periodically alternating change between an applied state in which the external magnetic field is applied to the MCE element **12** and an removed state in which the external magnetic field is removed from the MCE element **12**. The removed state may be referred to as a non-applied state in which the external magnetic field is not applied to the MCE element **12**. The motor **15** drives the pumps **41** and **42** of the heat transporting device **14**. Thereby, the pumps **41** and **42** generate the bidirectional flow of the primary medium for one MCE element **12**.

The pumps **41** and **42** produce the bidirectional flow of the primary medium in the MCD unit in order to make the MCE element **12** functions as the AMR cycle. The pumps **41** and **42** are displacement-type bidirectional flow pumps. The pumps **41** and **42** are cam-plate type piston pumps. The pumps **41** and **42** are axial piston pumps having a plurality of cylinders. One cylinder of the pump **41** and one cylinder of the pump **42** are arranged to one MCE element **12**. Two cylinders arranged on one MCE element **12** functions complementarily. Thereby, the pumps **41** and **42** supply the bidirectional flow of the primary medium flowing along the longitudinal direction of one MCE element **12**. In this embodiment, the MHP apparatus **11** has a plurality of MCE elements **12** which are connected in thermally parallel. In the MHP apparatus **11**, eight MCE elements **12** are connected in thermally parallel. Therefore, each one of the pumps **41** and **42** has 8 cylinders.

The MHP apparatus **11** has a housing **21** which may be called as a circular cylindrical or a circular columnar shape. The housing **21** supports the rotary shaft **22** rotatably on a central axis of the housing **21**. The rotary shaft **22** is connected with the output shaft of the motor **15**. The housing **21** defines an accommodation chamber **23** for accommodating the MFM device **13** around the rotary shaft **22**. The accommodation chamber **23** is formed in a shape like a circular columnar shape. A rotor core **24** is fixed to the rotary shaft **22**. The rotor core **24** and the housing **21** provide yoke members for guiding and passing the magnetic flux. The rotor core **24** is configured to form a range which is easy to pass through the magnetic flux along the circumferential direction thereof and a range which is hard to pass through the magnetic flux. A permanent magnet **25** is fixed to the rotor core **24**. A plurality of magnets **25** are fixed on the rotor core **24**. The permanent magnet **25** is formed in a semi-cylindrical shape which has a fan-shaped cross section. The permanent magnet **25** is fixed on a radial outside surface of the rotary shaft **22**.

The rotor core **24** and the permanent magnet **25** form regions around them. One region is that the external magnetic field provided by the permanent magnet **25** is strong. The other one region is that the external magnetic field provided by the permanent magnet **25** is weak. In the region in which the external magnetic field is weak, a state in which the external magnetic field is almost completely removed is provided. The rotor core **24** and the permanent magnet **25** rotate in a synchronizing manner with a revolution of the rotary shaft **22**. Therefore, the region of strong external magnetic field and the region of weak external magnetic field rotate synchronously with the revolution of the rotary shaft **22**. As a result, at one point on a circumference of the rotor core **24** and the permanent magnet **25**, a period when the external magnetic field is strongly applied and a period when the external magnetic field becomes weak and was almost removed are alternately appears. Therefore, the rotor core **24** and the permanent magnet **25** provide the MFM device **13** which alternates the applied state and the removed state of the external magnetic field. The rotor core **24** and the permanent magnet **25** provide a device which alternately switches the state applying the external magnetic field to the MCE element **12** and the state removing the external magnetic field from the MCE element **12**. The word of the magnetic field is interchangeable with magnetic flux density or magnetic field strength.

The housing **21** defines at least one work chamber **26**. The work chamber **26** is located next to the accommodation chamber **23**. The housing **21** defines a plurality of work chambers **26** arranged at equal intervals on a radial outside of the accommodation chamber **23**. In this embodiment, one housing **21** defines eight work chambers **26**. Each of the work chambers **26** forms a columnar-shaped chamber which has a longitudinal direction along the axial direction of the housing **21**. One work chamber **26** is formed so that it corresponds to one cylinder of the pump **41** and one cylinder of the pump **42**. Two cylinders are arranged on both sides of one work chamber **26**.

The work chamber **26** provides a channel where the primary medium flows. The primary medium flows along a longitudinal direction of the work chamber **26**. The primary medium flows along a longitudinal direction of the work chamber **26** in a bidirectional manner in which flow directions are alternately switched in one direction and the other opposite direction.

The work chamber **26** also provides an accommodation chamber in which the MCE element **12** is accommodated. The housing **21** provides a container in which the work chamber **26** is formed. The MCE element **12** which provides a magnetic working material having magneto-caloric effect is disposed in the work chamber **26**.

One MCE element **12** is formed in a columnar shape, i.e., a rod shape, having a longitudinal direction along an axial direction of the MHP apparatus **11**. The MCE element **12** is formed in a shape which can provides sufficient heat exchange with the primary medium flowing through within the work chamber **26**. Each NICE element **12** may also be called an element bed.

The MCE element **12** is placed under an effect of the external magnetic field switched between an applied state and a removed state by the MFM device **13**. That is, as the rotary shaft **22** rotates, it is performed to switch the applied state in which the external magnetic field for magnetizing the MCE element **12** is applied and the removed state in which the external magnetic field is removed from the MCE element **12**.

As shown in FIG. **3**, an angular range PM where the permanent magnet **25** is disposed along circumferential direction is shorter than an angular range PN where the permanent magnet **25** is not disposed. The permanent magnet **25** is fixed on a radial outside of the rotary shaft **22**. An occupying rate of the permanent magnet **25** along a circumferential direction on a plan perpendicular to the rotary shaft **22** is smaller than ½ of the periphery.

The angular range PM may be referred to as an applying period in which the external magnetic field is applied to one MCE element **12**, i.e., a magnetized period PM. The MFM device **13** has the permanent magnet **25** that has a size corresponding to the magnetized period PM. The angular range PN may also be referred to as a removal period in which the external magnetic field is removed from one MCE element **12**, i.e., a demagnetized period PN. Demagnetization does not mean condition where magnetic field is zero. Demagnetization includes condition where magnetic field, which is weaker than magnetic field in the magnetized period PM, is still applied. By setting the magnetized period PM shorter than the demagnetized period PN (PM<PN), the angular range PM in which the permanent magnet **25** is disposed can be reduced. Thereby, it is possible to down size the permanent magnet **25** and the rotor core **13**. It is possible to reduce weight of the permanent magnet **25** and the rotor core **13**. In other words, it is possible to reduce weight of the magnetism source for applying the external magnetic field to the MCE element **12**.

The angular range PM is shorter than ¾ of the angular range PN. Since the magnetized period PM is shorter than ¾ of the demagnetized period PN (PM<¾PN), it is possible to enlarge advantage of weight reduction and/or down sizing.

Corresponding to the magnetized period PM is set up shorter than the demagnetized period PN, a discharge and suction characteristic of the pumps **41** and **42** also set up asymmetrically. Since the MCE element **12** generates heat in the magnetized period PM, the pumps **41** and **42** are operated to make the primary medium flows toward the high-temperature system **16**. On the other hand, since the MCE element **12** absorbs heat in the demagnetized period PN, the pumps **41** and **42** are operated to make the primary medium flows toward the low-temperature system **17**. Since the magnetized period PM is shorter than the demagnetized period PN, a first period in which the primary medium flows toward the high-temperature system **16** is shorter than the second period in which the primary medium flows toward the low-temperature system **17**. The magnetized period PM and the first period overlap in major range of them. The magnetized period PM and the first period may shift slightly at a starting range and an ending range of them. The demagnetized period PN and the second period overlap in major range of them. The demagnetized period PN and the second period may shift slightly at a starting range and an ending range of them. A flow amount of the primary medium flowing toward the high-temperature system **16** in the first period and a flow amount of the primary medium flowing toward the low-temperature system **17** in the second period are equal. The heat transporting device **14** provides the same flow amounts in each of flow directions of the bidirectional flow FM, FN. Although the first period is short, it is desirable to be performed sufficient heat exchange between the MCE element **12** and the primary medium in the first period.

FIGS. **4** and **5** show a heat exchange portion **61** formed on the MCE element **12**. FIG. **5** shows a cross section on a V-V line shown in FIG. **4**. The MCE element **12** has a heat exchange portion **61** which performs heat exchange with the heat transport medium. The heat exchange portion **61** provides different heat exchanging efficiencies in one flow direction FM and in the other flow direction FN out of the bidirectional flow FM, FN. The heat exchange portion **61** has a configuration that presents asymmetrical different profiles against each of flow directions of the bidirectional flow FM, FN. The heat exchange portion **61** has a triangular pole-shaped projection **62**. The MCE element **12** has a plurality of projections **62**. The plurality of projections **62** defines a channel **63** for the primary medium around the projections **62**. The projection **62** is positioned to direct one apex toward the high-temperature system **16**. The projection **62** of the heat exchange portion **61** is arranged so that one side surface, i.e., a base surface, is directed toward the low-temperature system **17**.

The flow FN which flows to the low-temperature system **17** in the demagnetized period PN collides with the apex of the projection **62**. The flow FN flows smoothly along slant surfaces of the projection **62**. On the other hand, the flow FM which flows toward the high-temperature system **16** in the magnetized period PM collides with the base surface of the projection **62**. The flow FM is impeded by colliding onto the base surface of the projection **62**. The flow FM produces turbulences around the projection **62**.

The heat exchange portion **61** creates and provides higher pressure loss in the flow FM than that in the flow FN. The heat exchange portion **61** provides higher pressure loss of the heat transport medium in the magnetized period PM than that in the demagnetized period PN.

The heat exchange portion **61** provides higher heat exchanging efficiency in the flow FM than that in the flow FN. The heat exchange portion **61** provides higher heat exchanging efficiency in the flow FM of the primary medium in the magnetized period PM, i.e., in the flow FM toward the high-temperature system **16**, than that in the flow FN in an opposite direction. The heat exchange portion **61** performs higher heat exchanging efficiency with the heat transport medium in the magnetized period PM than heat exchanging efficiency in the demagnetized period PN. The heat exchange portion **61** provides different heat exchanging efficiencies according to the flow directions of the heat transport medium. According to this arrangement, since it is possible to provide higher heat exchanging efficiency in the magnetized period PM than that in the demagnetized period PN, it is possible to obtain a large heat exchanging quantity even in the magnetized period PM that is short. Thereby, it is possible to obtain a necessary heat exchanging quantity between the MCE element **12** and the primary medium even in the first period that is short. Even if the apparatus uses the MFM device **13** that provides the magnetized period PM shorter than the demagnetized period PN, it is possible to obtain a required heat exchanging quantity in the bidirectional flow FM and FN of the heat transport medium.

In this embodiment, a flow amount in the flow FM and a flow amount in the flow FN, i.e., a moving amount of the primary medium in both directions are the same each other. A flow velocity of the flow FM and the flow velocity of the flow FN may be adjusted by changing a discharging characteristic and/or a drawing characteristic of the pumps **41** and **42**.

Width WD of the projection **62** may be set within a range between 0.1 mm to 0.5 mm. Width GP of the channel **63** may be set within a range between 0.1 mm to 0.5 mm. Length ML of the MCE element **12** in the flow direction may be set within a range between 100 mm to 300 mm.

As the MHP apparatus **11** is activated and operated, applying the external magnetic field to the MCE element **12** and removing the external magnetic field from the MCE element **12** are alternately repeated periodically. Thereby, the MCE element **12** generates heat dissipation and heat absorption alternately. The pumps **41** and **42** generate the bidirectional flow of the primary medium in a synchronizing manner with the heat dissipation and the heat absorption on the MCE element **12**. Thereby, heat is transferred around the MCE element **12**.

By operating the MHP apparatus **11** in the above-mentioned way, the MCE element **12** disposed in the MHP apparatus **11** gets high temperature at the high temperature end and gets low temperature at the low temperature end. The MHP apparatus **11** supplies warm temperature to the high-temperature system **16** operatively disposed on and thermally connected with the high temperature end. The MHP apparatus **11** supplies cold energy to the low-temperature system **17** disposed on the low temperature end.

According to this embodiment, it is possible to provide a light-weight MHP apparatus **11** by setting the magnetized period PM shorter than the demagnetized period PN. According to this embodiment, it is possible to provide a small MHP apparatus **11** by setting the magnetized period PM shorter than the demagnetized period PN. The heat exchange portion which varies heat exchanging efficiency depending on flow directions of the primary medium is disposed between the magneto-caloric element **12** and the primary medium. Thereby, it is possible to obtain a necessary heat exchanging quantity between the MCE element **12** and the primary medium even in the configuration in which the magnetized period PM is shorter than the demagnetized period PN.

## Second Embodiment

This embodiment is one of modifications based on a basic form provided by the preceding embodiment. The preceding embodiment employs the triangular pole-shaped projection **62**. Alternatively, the heat exchange member may employ various configurations of which heat exchanging efficiency changes according to the flow direction of the primary medium. As shown in FIG. **6**, this embodiment employs a heat exchange portion **261**. The heat exchange portion **261** has projections **262** each of which is formed in a semi-circular columnar shape. The projections **262** provides higher heat exchanging efficiency in the flow FM than that in the flow FN. The heat exchange portion **261** has a configuration that presents asymmetrical different profiles against each of flow directions of the bidirectional flow FM, FN.

## Third Embodiment

This embodiment is one of modifications based on a basic form provided by the preceding embodiment. In the preceding embodiments, the heat exchange portion **61** and **261** are provided by a static heat exchange portion. Alternatively, in this embodiment, the heat exchange portion **361** having a dynamic heat exchange member which can actively move in response to the flow of the primary medium is employed. The heat exchange portion **361** is capable of changing shapes in each of flow directions of the bidirectional flow FM, FN. The heat exchange portion **361** has a configuration that becomes and presents asymmetrical profiles on each of flow directions of the bidirectional flow FM, FN.

FIG. **7** shows condition of a heat exchange portion **361** in the demagnetized period PN. FIG. **8** shows condition of the heat exchange portion **361** in the magnetized period PM. As illustrated, the heat exchange portion **361** has a plurality of movable members **364**, which are disposed on the MCE element **12**, for performing heat exchange. The movable member **364** is formed in a shape like a semi-circular columnar shape. The movable member **364** is arranged on a boundary between the channel **63** and the MCE element **12**. The movable member **364** is a part of the MCE element **12**. The movable member **364** is rotatably supported, in a rocking manner, on a main part of the MCE element **12**. The movable member **364** is movable to a first position and a second position by an actuating mechanism **365**. The actuating mechanism **365** may be provided by actuators, such as a motor and electro-magnetic solenoid, and a mechanical linkage which links between the actuator and the movable member **364**. The controller **18** may control the actuator so that the actuator moves the movable member **365** in a synchronized manner with a revolution of the motor **15**.

In the first position shown in FIG. **7**, the movable member **364** generates and obtains small pressure loss in the flow FN of the primary medium. In the first position, the movable member **364** provides low heat exchanging efficiency to the flow FN of the primary medium. In the first position, the movable member **364** provides small irregularities on the surface of the MCE element **12**.

In the second position illustrated in FIG. **8**, the movable member **364** generates and obtains large pressure loss to the flow FM of the primary medium. In the second position, the movable member **364** provides high heat exchanging efficiency to the flow FM of the primary medium. In the second position, the movable member **364** provides large irregularities on the surface of the MCE element **12**. The irregularities in the second position are larger than the irregularities in the first position. According to this configuration, the heat exchange portion **361** demonstrates higher heat exchanging efficiency in the flow FM than that in the flow FN.

## Fourth Embodiment

This embodiment is one of modifications based on a basic form provided by the preceding embodiment. The heat exchange portion **361** which is movable by an actuating mechanism is provided in the preceding embodiment. Alternatively, in this embodiment, the heat exchange portion **461** having a dynamic heat exchange member which can passively move in response to the flow of the primary medium is employed. The heat exchange portion **461** is capable of changing shapes in each of flow directions of the bidirectional flow FM, FN. The heat exchange portion **461** has a configuration that becomes and presents asymmetrical profiles against each of flow directions of the bidirectional flow FM, FN.

FIG. **9** shows condition of the heat exchange portion **461** in the demagnetized period PN. FIG. **10** shows condition of the heat exchange portion **461** in the magnetized period PM. As illustrated, the heat exchange portion **461** has a plurality of movable members **466**, which are disposed on the MCE element **12**, for performing heat exchange. The movable member **466** is formed in a shape like a fin. The movable member **466** is arranged on a boundary between the channel **63** and the MCE element **12**. The movable member **466** is a part of the MCE element **12**. The movable member **466** is rotatably supported, in a hinge-like manner, on a main part of the MCE element **12**. The movable member **466** is movable to a first position and a second position by receiving the flow of the primary medium.

In the first position illustrated in FIG. **9**, the movable member **466** obtains small pressure loss to the flow FN of the primary medium. In the first position, the movable member **466** provides low heat exchanging efficiency to the flow FN of the primary medium. In the first position, the movable member **466** provides small irregularities on the surface of the MCE element **12**.

In the second position illustrated in FIG. **10**, the movable member **466** obtains large pressure loss to the flow FN of the primary medium. In the second position, the movable member **466** provides high heat exchanging efficiency to the flow FN of the primary medium. In the second position, the movable member **466** provides large irregularities on the surface of the MCE element **12**. According to this structure, the heat exchange portion **461** demonstrates higher heat exchanging efficiency in the flow FM than that in the flow FN.

## Fifth Embodiment

This embodiment is one of modifications based on a basic form provided by the preceding embodiment. In the preceding embodiments, the MCE element **12** provides the heat exchange portion by an outside profile of itself. Alternatively, in this embodiment, the apparatus has a heat exchange portion **561** which varies heat exchanging efficiency depending on flow directions of the primary medium by vibrating the MCE element **12**. The heat exchange portion **561** has a vibrator **567** which provides different vibrating state on the NICE element **12** in each of flow directions of the bidirectional flow FM, FN.

FIG. **11** shows the perspective view of the MCE element **12**. The NICE element **12** has a plurality of plate-shaped wall members **562** arranged in parallel each other. The wall members **562** define channels **563** for the primary medium on the wall members **562**. The heat exchange portion **561** has a vibrator **567** which vibrates the MCE element **12**. The vibrator **567** is an ultrasonic transducer. The vibrator **567** is disposed on a side surface of the MCE element **12** to vibrate the wall members **562**. The vibrator **567** does not vibrate the MCE element **12** or vibrate small in the demagnetized period PN. The vibrator **567** vibrates the MCE element **12** greatly in the magnetized period PM. Thereby, the heat exchanging efficiency between the MCE element **12** and the primary medium is increased to be higher in the magnetized period PM than the demagnetized period PN. The controller **18** may control the vibrator **567** so that the vibrator **567** is activated and deactivated in a synchronized manner with a revolution of the motor **15**. For example, the controller **18** deactivate the vibrator **567** to stop vibration when the primary medium flows in the direction shown by the symbol PM, and activate the vibrator **567** to supply vibration when the primary medium flows in the direction shown by the symbol PN. According to this configuration, the heat exchange portion **561** demonstrates higher heat exchanging efficiency in the flow FM than that in the flow FN.

## Sixth Embodiment

This embodiment is one of modifications based on a basic form provided by the preceding embodiment. In the embodiments, pumps **41** and **42** are arranged on both ends of the MCE element **12**. Alternatively, in this embodiment, two MCE elements **12***a* and **12***b* are used. A pump **643** is arranged between the MCE elements **12***a* and **12***b*.

As shown in FIG. **12**, the MHP apparatus **11** has two MCE elements **12***a* and **12***b*. The heat transporting device **14** has the pump **643** arranged between two MCE elements **12***a* and **12***b*. The pump **643** generates flow of the primary medium to pass through both of the MCE elements **12***a* and **12***b*. The pump **643** may be provided by a radial piston pump. According to this embodiment, the primary medium can be supplied to two MCE elements **12***a* and **12***b* by using one pump **643**.

## Other Embodiments

The present disclosure is not limited to the above embodiments, and the present disclosure may be practiced in various modified embodiments. The configuration, function, and advantages of the above described embodiments are just examples. The technical scope of the present disclosure shall not be limited by the above descriptions. The present disclosure is not limited to the above combination, and disclosed technical means can be practiced independently or in various combinations. Some extent of the disclosure may be shown by the scope of claim, and also includes the changes, which is equal to and within the same range of the scope of claim.

In the embodiments, the multi-cylinder pump is provided by the swash plate type pump or the radial piston pump. Alternatively, the other type of displacement pump may be used. In the first embodiment, one work chamber is disposed to be associated with one cylinder of the pump. Alternatively, a plurality of cylinders and one work chamber may be disposed to be associated with, one cylinder and a plurality of work chambers may be disposed to be associated with, or a plurality of cylinders and a plurality of work chambers may be disposed to be associated with.

In the preceding embodiments, the present disclosure is applied to the air-conditioner for vehicle. Alternatively, the present disclosure may be applied to an air-conditioner for residences. Further alternatively, the present disclosure may be utilized to provide a hot-water-supply apparatus which heats water. In the embodiments, the MHP apparatus **11** uses the outside air as the main heat source. Alternatively, the other heat sources, such as water or soil, may be used as the main heat source.

In the preceding embodiments, the MHP apparatus **11** is shown as one example of the thermo-magnetic cycle apparatus. Alternatively, the present disclosure may be applied to a thermo-magnetic engine apparatus which is another one of the thermo-magnetic cycle apparatus. For example, a thermo-magnetic engine apparatus can be provided by adjusting the phase angle of the magnetic-field change and the heat transport medium flow on the MHP apparatus **11**.

In the preceding embodiments, a pump that performs the suction process and the discharge process complementarily is employed to generate a bidirectional flow, i.e., a reversible flow or an alternating flow of the heat transport medium. The present disclosure is not limited to use such a pump. The present disclosure may be applied to an apparatus that generates the bidirectional flow by using a unidirectional flow pump and valves, for example.

In the preceding embodiments, the external magnetic field is modulated by relatively moving the permanent magnet to the magneto-caloric element. The present disclosure is not limited to use such a magnetic field modulating device. The present disclosure may be applied to an apparatus that modulates the external magnetic field by relatively moving the magneto-caloric element to the permanent magnet.

For example, means and functions of the control device **10** may be provided by only software, only hardware or a combination of the software and the hardware. For example, the control device may be made of an analogue circuit.

What is claimed is:

**1**. A thermo-magnetic cycle apparatus comprising:

a magneto-caloric element which generates heat dissipation and heat absorption in response to strength change of an external magnetic field; and

a magnetic field modulating device which modulates the external magnetic field so that a magnetized period, when the magneto-caloric element is placed in a strong external magnetic field, and a demagnetized period, when the magneto-caloric element is placed in a weak external magnetic field which is weaker than that in the magnetized period, are periodically altered, and so that the magnetized period is shorter than the demagnetized period.

**2**. The thermo-magnetic cycle apparatus in claim **1**, further comprising:

a heat transporting device which generates flow of the heat transport medium so that the heat transport medium flows along the magneto-caloric element and performs heat exchange with the magneto-caloric element, the flow of the heat transport medium being a bidirectional flow switched alternately synchronizing with change of the external magnetic field by the magnetic field modulating device, wherein

the magneto-caloric element has a heat exchange portion which performs heat exchange with the heat transport medium.

**3**. The thermo-magnetic cycle apparatus in claim **2**, wherein

the heat exchange portion performs higher heat exchanging efficiency with the heat transport medium in the magnetized period than heat exchanging efficiency in the demagnetized period.

**4**. The thermo-magnetic cycle apparatus in claim **2**, wherein

the heat exchange portion performs different heat exchanging efficiencies according to the flow directions of the heat transport medium.

**5**. The thermo-magnetic cycle apparatus in claim **2**, wherein

the heat exchange portion provides higher pressure loss of the heat transport medium in the magnetized period than that in the demagnetized period.

**6**. The thermo-magnetic cycle apparatus in claim **2**, wherein

the heat exchange portion has a configuration that presents asymmetrical profiles against each of flow directions of the bidirectional flow.

**7**. The thermo-magnetic cycle apparatus in claim **6**, wherein

the heat exchange portion is capable of changing shapes in each of flow directions of the bidirectional flow.

**8**. The thermo-magnetic cycle apparatus in claim **2**, wherein

the heat exchange portion has a vibrator which provides different vibrating state on the magneto-caloric element in each of flow directions of the bidirectional flow.

**9**. The thermo-magnetic cycle apparatus in claim **1**, wherein

the heat transporting device provides the same flow amounts in each of flow directions of the bidirectional flow.

**10**. The thermo-magnetic cycle apparatus in claim **1**, wherein

the magnetized period is shorter than ¾ of the demagnetized period.

**11**. The thermo-magnetic cycle apparatus in claim **1**, wherein

the magnetic field modulating device has a permanent magnet that has a size corresponding to the magnetized period.

**12**. The thermo-magnetic cycle apparatus in claim **11**, wherein

the permanent magnet is fixed on a radial outside of a rotary shaft to occupy a range extending in a circumferential direction, a circumferential occupying rate of the permanent magnet on a plan perpendicular to the rotary shaft is smaller than ½.

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